GIS Supported Hydrogeological Analysis of the Tola Municipio, Nicaragua

James K. Adamson, PG

2014 Paper No. 36-5: Geological Society of America, 126th Annual Meeting, Vancouver

Background

Objectives & Approach

Objectives
The Tola municipio of Nicaragua is a unique 477 km^2 area along Nicaragua's Pacific coast that has a history of water access and water quality issues. The region is experiencing economic development resulting from a surging tourism industry and the proposed canal which is planned in the southern portion of the municipio. With this context, the main objective of this analysis is to summarize the regional groundwater environments to support humanitarian and economic development initiatives.

Approach
Research, field reconnaissance, mapping and geospatial analysis were performed to characterize the hydrogeological environments and groundwater quality of Tola at a regional scale. This data was integrated into a unique GIS model that assesses the degree of shallow groundwater potential throughout Tola. The model provides a qualitative estimation of favorability on the basis of the hydrogeological environment, water quality conditions, vulnerability and morphological aptitude of the landscape. The results provide a transitional planning-level tool that can be applied to support informed decision making to improve water security and minimize failed investments.

Study Area of Tola

Tola
The Tola Municipio covers 477 km^2 and is located in the department of Rivas, approximately 120 km south of Nicaragua's capital Managua. Tola is bordered to the north by the Bethlehem municipio and by the Rivas and San Juan del Sur municipios to the east. The Pacific Ocean bounds the southwest of Tola.

Climate
The average annual temperature is 27°C and ranges from 19.5°C to 36°C. Annual rainfall ranges between 1200-1400 mm / year. The dry season spans February through April where monthly rainfall ranges from 2 - 20 mm/month. Between June and October, rainfall averages from 100 to 200 mm / month (Tola Meteorological Station 1970 - 2010).

Relief
The relief is an important aspect that influences the hydrogeology of Tola. The uplift of sedimentary rocks is greatest in the northeastern portion of Tola where elevations reach up to 140 meters. The broad sloping uplands and hills are dissected by steep drainages that flow southwest towards the Pacific Coastal Plain of Nicaragua. The plain is relatively flat and generally less than 15 meters in elevation and spans the entire length of Tola along the Pacific Ocean.

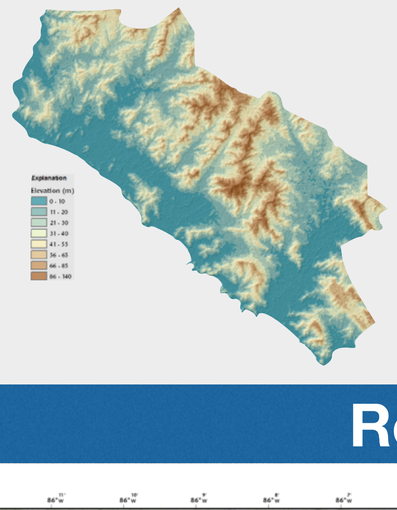
Geology
The primary rock formations in Tola are the Rivas and Brito formations of Cretaceous and Paleogene age, respectively. These formations consist of sandstones, shales, marls, conglomerates, mudstones and siltstones. Beds of hard graywacke and igneous lavas are also present in both the Brito and Rivas formations. The thickness of the Brito formation has been estimated up to 3,000 meters in some areas, whilst the older Rivas formation is believed to reach thicknesses up to 3,400 meters. These formations are regionally dipping westerly at angles ranging form 5 to 30 degrees. In southeast Tola, a Cretaceous-aged igneous intrusion is present consisting of hard andesite with a band of metamorphic and weathered rock around it. Quaternary-aged alluvial sands, gravels and silts cover approximately 17% of Tola and overlie the Rivas and Brito formations.

Groundwater
Groundwater environments are summarized in Table 1. A majority of the groundwater resources are within Quaternary-aged unconsolidated alluvial deposits or the Paleogene-aged Brito formation. Groundwater of meager to small yields is typically available in the Brito and Rivas formations; larger yields are limited to fracture networks and sandstone beds of higher permeability. Groundwater flow conditions are considered favorable due to the relatively uniform westerly dipping geological structure. Saltwater intrusion is a major factor along the coast due to the relatively low permeability of the Brito formation.

Table 1 - Groundwater Environments in Tola

	% of Tola	Groundwater Potential	Notes
Quaternary Unconsolidated Sedimentary	17	Good	Gravels and sand layers support aquifers bounded by silt and clay interbeds. Meager to very large yields possible.
Quaternary & Paleogene Colluvium and Shallow Weathered Bedrock	9	Moderate to Good	Unconsolidated colluvium, weathered bedrock & shallow fracture zones that often support localized aquifer systems. Unsuitable to moderate yields possible.
Paleogene Brito Formation	60	Moderate	Consolidated sedimentary & crystalline formations of moderate to high permeability: Good groundwater potential in sandstone, conglomerate, carbonate and marl beds. Poor potential in shales, mudstones and siltstones. Yields are highly dependent on formation permeability & fracture zones. Difficult drilling conditions in igneous lavas and greywacke beds.
Cretaceous Rivas Formation	13	Moderate	
Cretaceous Igneous Intrusion	1.5	Poor	Hard crystalline formations and metamorphic zones with poor groundwater potential. Unsuitable to small yields possible in localized fracture zones resulting from the intrusion and geologic structure. Hard rock drilling should be expected.

Topographic Relief of Tola



Material & Methods

Input Data & Field Reconnaissance

The desk study research assimilated existing geological, hydrogeological and water quality data from Tola. Following the desk study and data gap analysis, two reconnaissance missions were performed to fill gaps and characterize the regional hydrogeological environments. The first reconnaissance was performed by the **National Autonomous University of Nicaragua** and included surveying of select wells and chemical laboratory water quality analysis. A second, 1-week reconnaissance was led by the author and included characterization of rock outcrops, springs and wells throughout Tola to support the analysis and to gain knowledge to support future well drilling efforts of Living Water International.


Survey & Characterization of Water Wells


Outcrop Characterization & Geological Mapping


Characterization of Springs and Water Features

Layer Development With ArcGIS Spatial Analyst

Based on the desk study and reconnaissance, a series of geospatial layers were developed to support the analysis. The three primary layers developed included morphological aptitude, water quality/ geochemistry and geology.

Morphological Aptitude/TPI Index
A topographic position index (TPI) analysis was performed using slope and elevation data derived from the ASTER 30m Global Digital Elevation Model (GDEM). The TPI analysis was adapted from methodologies defined by Weiss (2001) and Jenness (2007). A 500-meter small neighborhood slope position classification was established based on TPI values of individual 30x30 meter raster cells. TPI values ranging from -5 to +6 were classified into 6 categories ranging from low to high in terms of hydrogeological favorability.

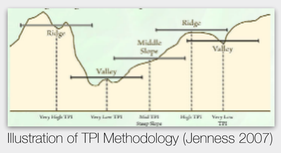
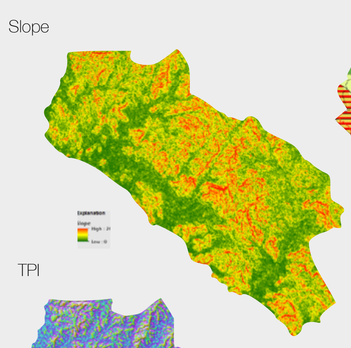
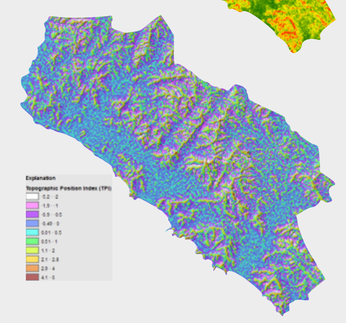


Illustration of TPI Methodology (Jenness 2007)

Slope



TPI



Water Quality & Geochemistry
Assimilation of existing data, maps and recently collected data from the field reconnaissance. Constituents of concern included total dissolved solids, boron, nitrogen and coliform bacteria. A higher resolution map and legend is shown in the results section.

Updated Geological Mapping
Existing department scale geological maps were compiled and modified based on the results of the 1-week field reconnaissance. A higher resolution map and legend is shown in the results section.

Algorithms Applied with Python Code in ArcGIS

Hydrogeological Favorability Analysis
A matrix was developed to define hydrogeological favorability based on two factors (i) Morphological Aptitude and (ii) Geological Suitability.

Geological suitability was determined through geospatial modeling and analysis of geology, geochemistry, water quality, mapped formation permeability and mapped rock hardness. These datasets were developed through the desk study and reconnaissance period.

The two resulting layers were intersected in ArcGIS and prepared for the next step of analysis.

Geological Suitability (High → Low) \ Morphological Aptitude / TPI (High +6 → Low -5)	Ridges	Steep Slopes	Upper Slopes	Lower Slopes	Gentle Slopes	Valleys
Very Good	3	3	3	1	1	1
Good	5	4	4	2	2	2
Mod.	5	4	4	3	3	2
Low	5	5	4	4	4	3
V. Low	5	5	5	4	5	4

Hydrogeological Favorability Matrix

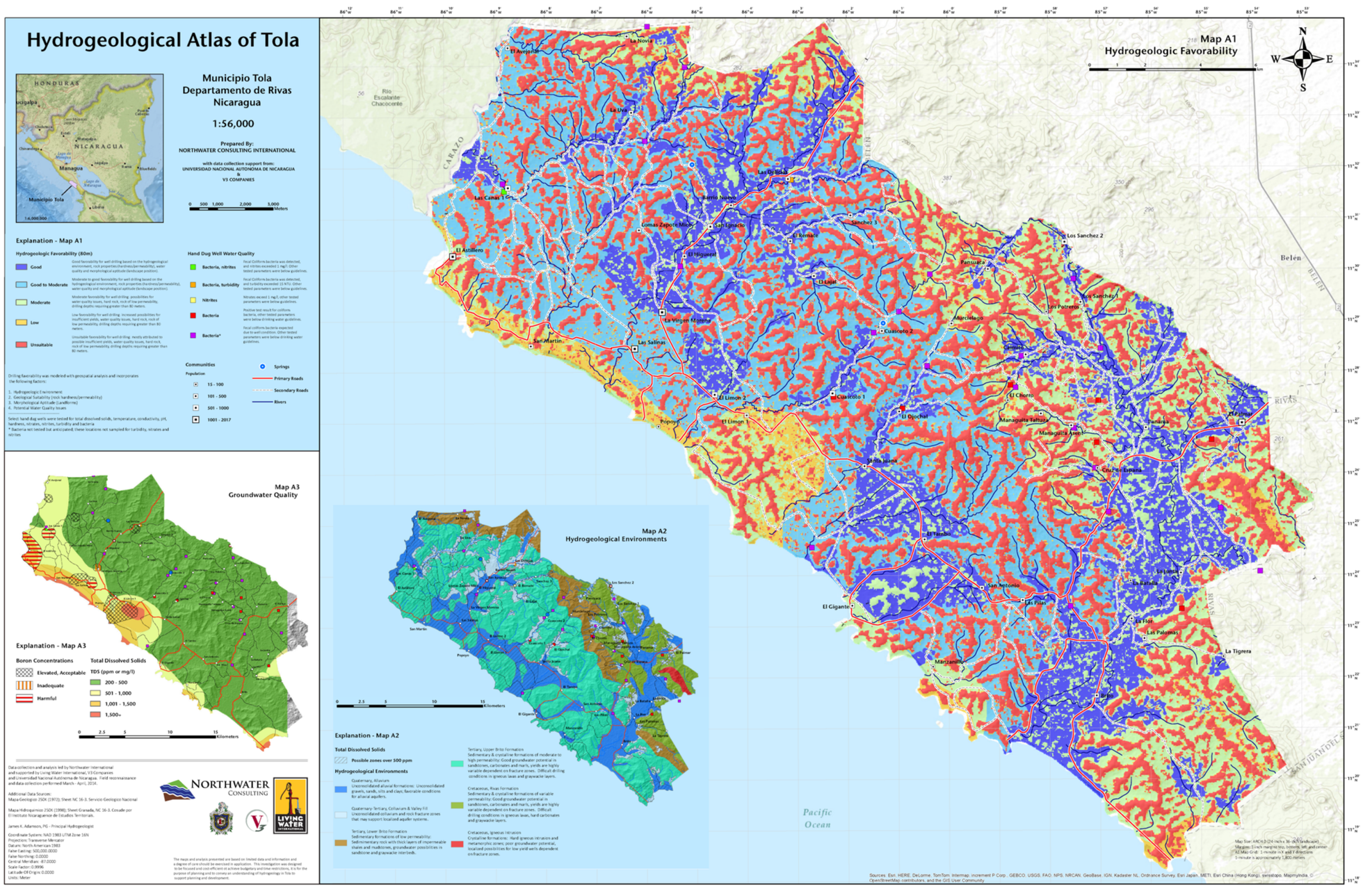
GIS Analysis
The matrix was programmed in Python language and applied into ArcGIS tools to develop a feature with hydrogeological favorability attributes.

```
#EXPRESSION

favorabilityCalc(!geo_suit!, !gridcode!)

#MATRIX CODE FOR HYDROGEOLOGICAL FAVORABILITY TOLA

def favorabilityCalc(geo_suit, gridcode):
  favMatrix = []
  favMatrix.append([0, 0, 0, 2, 2, 2])
  favMatrix.append([1, 1, 1, 3, 3, 4])
  favMatrix.append([2, 2, 2, 3, 3, 4])
  favMatrix.append([2, 3, 3, 4, 3, 4])
  favMatrix.append([3, 3, 4, 4, 4, 4])

  favDescriptions = ['Very good', 'Good', 'Moderate', 'Low', 'Unsuitable']

  favorability_value = favMatrix[int(geo_suit) - 1][int(gridcode) - 1]
  #return favorability_value
  return favDescriptions[favorability_value]
```

	Hydrogeological Favorability
1	Good
2	Good to Moderate
3	Moderate
4	Low
5	Unsuitable

Final Hydrogeological Favorability Ranking

Results



Contact & Credits

Acknowledgments

National Autonomous University of Nicaragua

Living Water International

Northwater Consulting International

Stuart Dykstra, V3 Companies

Benjamin Dykstra, Water Technologies International

Gary Lavanchy, University of Denver

Katherine Williams

Photos: Stuart Dykstra & James Adamson


Turbidite Sequence at Pilas


Howler Monkeys


Rope pump on hand dug well at public school


Playa Gigante, with "lomas" hills in the background

References/Sources

CIRA/UNAN. 2007. Evaluación del estado actual (calidad y cantidad) y estimación de la dinámica de recarga de los mantos freáticos en la franja costera del Municipio de Tola.

INETER.1998.Mapa Hidroquimico 250K; Sheet Granada, NC 16-3.

INETER. 2004. Hojas Topográficas. 50K

INETER. 1995. Mapa Geologico--minero. 25K

INETER. Registro de Estaciones Rivas y Tola. 1967--2010

INETER/MAGFOR. 1998. Estudio Hidrológicos e hidrogeológicos en la región del pacifico de Nicaragua, Chinandega-León y Nagarote.

Jenness, J. 2007. Topographic Position Index, An ArcView 3.X Tool For Analyzing The Shape of a Landscape. Poster Presentation.

Krásný, J.1995. Hidrogeología de la Zona Pacífica de Nicaragua. Nota Explicativa al Mapa Hidrogeológico a Escala 1:250,000

Servicio Geologico Nacional. 1972. Mapa Geologico 250K (1972); Sheet NC 16-3.

Weiss, A. 2001. Topographic Position Index and Landform Analysis. The Nature Conservancy.

Contact
James K. Adamson, PG
Email: adamsonjk@gmail.com
Tel USA: + 1.630.742.6836